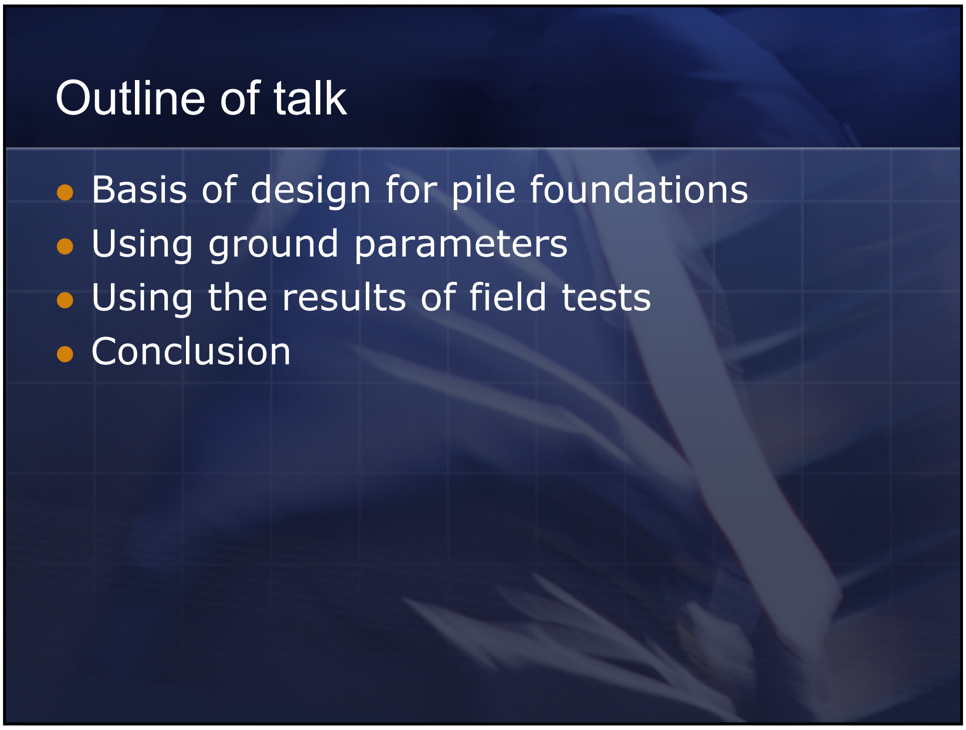
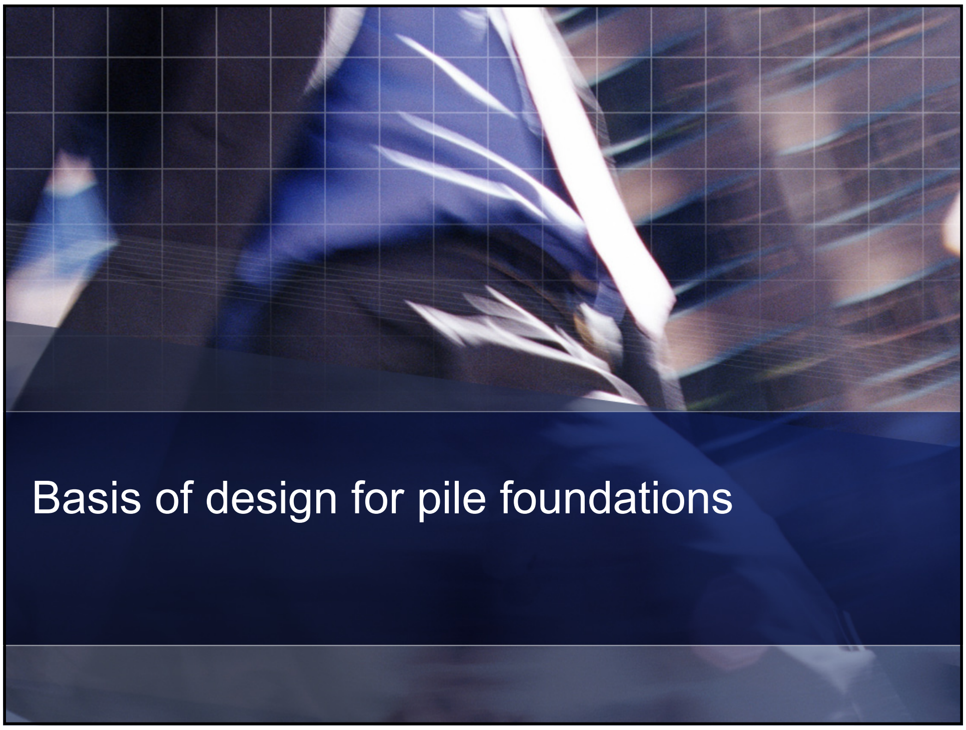
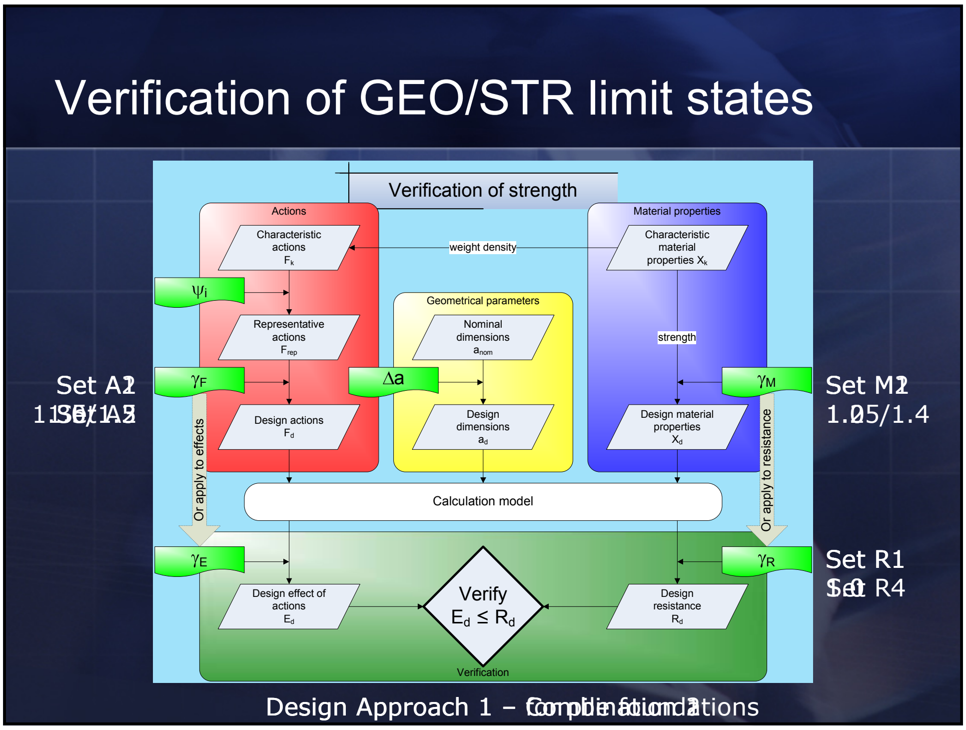

Pile design to Eurocode 7 & the UK National Annex
Dr Andrew Bond (Geocentrix)


Outline of talk
Basis of design for pile foundations
Using ground parameters
Using the results of field tests
Conclusion

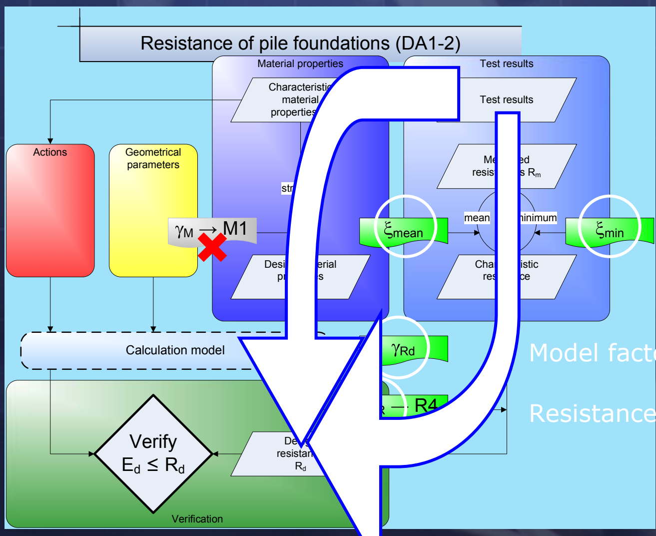


Basis of design for pile foundations



Verification of GEO/STR limit states
Verification of strength
Actions
Characteristic actions F_k
weight density
Material properties
Characteristic material properties X_k
ψ_i
Geometrical parameters
Representative actions F_{rep}
Nominal dimensions a_{nom}
strength
γ_F
Δa
γ_M
Design actions F_d
Design dimensions a_d
Design material properties X_d
Or apply to effects
Or apply to resistance
Calculation model
γ_E
γ_R
Design effect of actions E_d
Verify $E_d \leq R_d$
Design resistance R_d
Verification
Set A1
Set M1
1.25/1.4
Set R1
Set R4
Design Approach 1 –

Verification of strength: pile foundations



Using ground parameters

Pile resistance factors for DA1-2 (from draft BS NA to EN 1997-1)

Static load tests on piles loaded to...	Model factor (γ_{Rd})	Resistance factors from Set R4					
		Bored/CFA		Driven		Total (γ_t)	Tens-ion (γ_{st})
		Base (γ_b)	Shaft (γ_s)	Base (γ_b)	Shaft (γ_s)		
Eurocode							
ENV 1997-1: 1994	1.5	1.6/ 1.45	1.3	1.3		1.3-1.5	1.6
EN 1997-1: 2004	?						
BS National Annex to EN 1997-1							
Default values	**1.4**	**2.0**	**1.6**	**1.7**	**1.5**	As base	**2.0**
> 1% constructed piles taken to 1.5 x representative load (or settlement no concern)		1.7	1.4	1.5	1.3		1.7
Maintained load test to calculated unfactored ultimate load	1.2						

Case study – piles in sand

- Ground test results from site in Richmond (courtesy CL Associates, 2004)
  - 4 CPTs in dense (becoming loose gravelly) SAND
  - Design of 4 x 6m long piles x ϕ400mm bored piles
- Actions
  - Permanent G_k = 1400 kN + Variable Q_k = 500 kN

CPT number	Average q_c (MPa)		Angle of shearing resistance ϕ (°)		q_s (kPa)	q_b (kPa)
	1-4m	4-8m	1-4m	4-8m		
02	30	14	38-42 (say 40)	36-38 (say 37)	90 (assuming K_s = 2.0)	2650 (assuming $q_b/q_c \approx$ 0.2)
03	21	15				
05	27	9				
08	15	(15)				

Verification of ULS (DA1-2) – with no explicit verification of SLS

$$F_d = \gamma_G \times (V_G + W_G) + \gamma_Q \times V_Q$$
$$= 1.0 \times (1400 + 79) + 1.3 \times 500 = 2129kN$$

Design action
Factors from Set A2

Action factors

$$R_{b,calc} = q_b A_b = 2650kPa \times \left(\frac{\pi \times 0.4^2 m^2}{4} \right) = 333kN$$

$$R_{s,calc} = \overline{q_s} A_s = 90kPa \times (\pi \times 0.4m \times 6m) = 678kN$$

Conventional soil mechanics theory

$$R_d = \frac{R_{b,calc}}{\gamma_{Rd} \times \gamma_b} + \frac{R_{s,calc}}{\gamma_{Rd} \times \gamma_s}$$
$$= \left(\frac{333}{1.4 \times 2.0} + \frac{678}{1.4 \times 1.6} \right) \times 4 = 1686kN$$

Design resistance
Factors from Set R4

Model factor
Resistance factors

$F_d > R_d \rightarrow$ ULS NOT verified!

Verification of ULS (DA1-2) – with verification of SLS (but not ULS)

$$F_d = \gamma_G \times (V_G + W_G) + \gamma_Q \times V_Q$$
$$= 1.0 \times (1400 + 79) + 1.3 \times 500 = 2129kN$$

$$R_{b,calc} = q_b A_b = 2650kPa \times \left(\frac{\pi \times 0.4^2 m^2}{4} \right) = 333kN$$

$$R_{s,calc} = \overline{q_s} A_s = 90kPa \times (\pi \times 0.4m \times 6m) = 678kN$$

$$R_d = \frac{R_{b,calc}}{\gamma_{Rd} \times \gamma_b} + \frac{R_{s,calc}}{\gamma_{Rd} \times \gamma_s}$$
$$= \left(\frac{333}{1.4 \times 1.7} + \frac{678}{1.4 \times 1.4} \right) \times 4 = 1943kN$$

Resistance factors reduced

$F_d > R_d \rightarrow$ ULS NOT verified!

Verification of ULS (DA1-2)
– with verification of SLS and ULS

$$F_d = \gamma_G \times (V_G + W_G) + \gamma_Q \times V_Q$$
$$= 1.0 \times (1400 + 79) + 1.3 \times 500 = 2129kN$$

$$R_{b,calc} = q_b A_b = 2650kPa \times \left(\frac{\pi \times 0.4^2 m^2}{4}\right) = 333kN$$

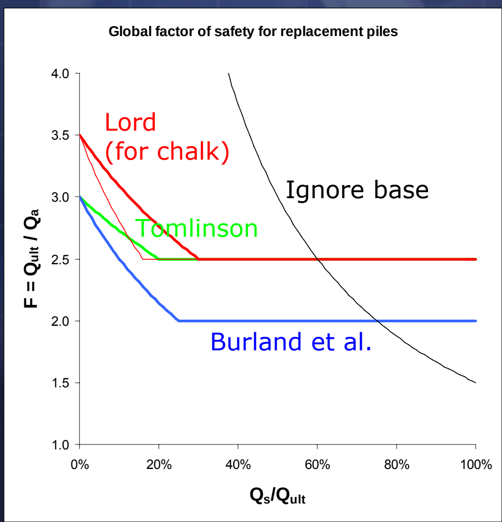
$$R_{s,calc} = \overline{q_s} A_s = 90kPa \times (\pi \times 0.4m \times 6m) = 678kN$$

$$R_d = \frac{R_{b,calc}}{\gamma_{Rd} \times \gamma_b} + \frac{R_{s,calc}}{\gamma_{Rd} \times \gamma_s}$$
$$= \left(\frac{333}{1.2 \times 1.7} + \frac{678}{1.2 \times 1.4}\right) \times 4 = 2267kN$$

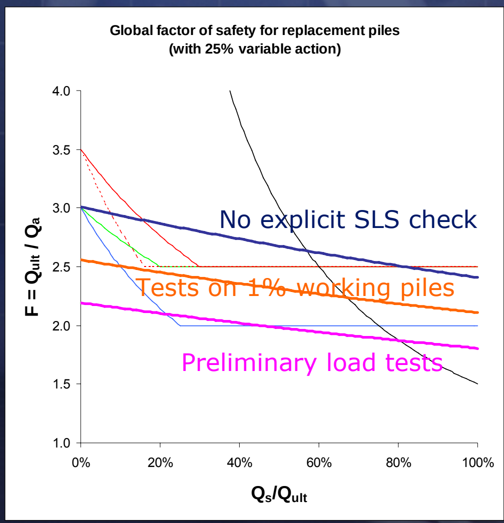
Model factor reduced

$F_d \leq R_d$ → ULS verified!

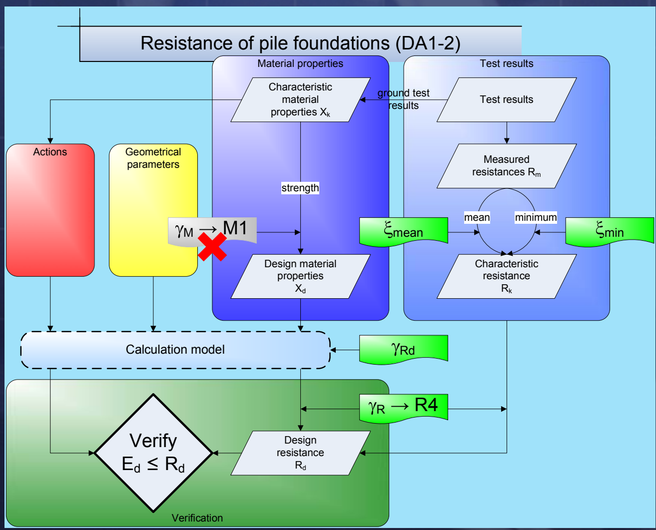
Traditional lumped factors of safety



Eurocode 7 vs traditional



Verification of strength: pile foundations



Correlation factors
from draft BS NA to EN 1997-1

Static load tests			Ground tests			Dynamic impact tests		
No	Mean	Min.	No	Mean	Min.	No	Mean	Min.
	ξ_1	ξ_2		ξ_3	ξ_4		ξ_5	ξ_6
1	1.55		1	1.55†		≥ 2	1.94	1.90
2	1.47	1.35	2	1.47†	1.39	≥ 5	1.85	1.76
3	1.42	1.23	3	1.42†	1.33	≥ 10	1.83	1.70
4	1.38	1.15	4	1.38	1.29	≥ 15	1.82	1.67
≥ 5	1.35	1.08	5	1.36	1.26	≥ 20	1.81	1.66
			(6)	(1.34)	(1.23)			
			7	1.33	1.20			
			(8)	(1.32)	(1.18)			
			(9)	(1.31)	(1.17)			
			≥ 10	1.30	1.15			

For stiff/strong structures that can transfer loads from "weak" to "strong" piles, ξ_1 to ξ_4 may be divided by 1.1 provided $\xi_i \geq 1.0$

Figures in (brackets) provide values "missing" from EN 1997

†Values chosen to match static load tests

Case study – piles in sand (revisited)

- Data from site in Richmond (courtesy CL Associates, 2004)
- 4 CPTs in dense (becoming loose gravelly) SAND
- Design of 4 x 6m long piles x ϕ400mm bored piles
- Actions: G_k = 1400 kN + Q_k = 500 kN

CPT number	Average q_c (MPa)		p_s (kPa)	p_b (kPa)	Calculated resistance (kN)		
	1-4m	4-8m			Shaft	Base	Total
02	30	14	120	2800	754	352	1106
03	21	15	120	3000	754	377	1131
05	27	9	100	2000	628	251	879
08	15	(15)	120	3000	754	377	1131

Verification of ULS (DA1-2)
– with verification of SLS (but not ULS)

$$F_d = \gamma_G \times (V_G + W_G) + \gamma_Q \times V_Q$$
$$= 1.0 \times (1400 + 79) + 1.3 \times 500 = 2129 kN$$

Design action
Factors from Set A2

$$R_k = \left(\frac{R_{calc,mean}}{\xi_{mean}}\right) or \left(\frac{R_{calc,min}}{\xi_{min}}\right)$$
$$= \left(\frac{1062}{1.38}\right) or \left(\frac{879}{1.29}\right) = 770\ or\ 681 = 681 kN$$

From statistical treatment of field test results

Minimum governs

Correlation factors for 4 test results

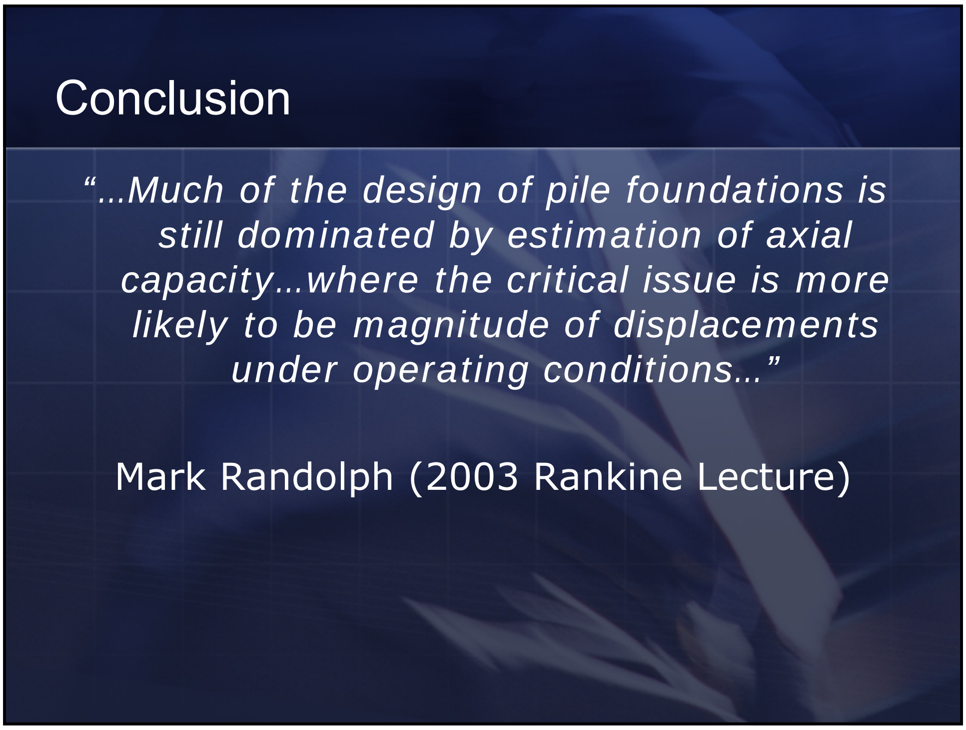
$$R_d = \frac{R_{b,calc}}{\xi_4 \times \gamma_b} + \frac{R_{s,calc}}{\xi_4 \times \gamma_s}$$
$$= \left(\frac{251}{1.29 \times 1.7} + \frac{629}{1.29 \times 1.4}\right) \times 4 = 1851 kN$$

Correlation factors
Resistance factors

Design resistance
Factors from Set R4
(1% working tests)

$F_d > R_d \rightarrow$ ULS NOT verified!


Conclusion


Conclusion
"...Much of the design of pile foundations is still dominated by estimation of axial capacity...where the critical issue is more likely to be magnitude of displacements under operating conditions..."
Mark Randolph (2003 Rankine Lecture)

‘Decoding the Eurocodes’ blog

- For a limited period, you can download this presentation from my ‘Decoding the Eurocodes’ blog
- Blog started May 2006
- Aim to post articles monthly
- www.eurocode7.com